Online Parameterization for WOFOST for United States Using Open Geospatial Standards

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***Abstract*— WOFOST (WOrld FOod STudies) is a well-known, widely applied simulation model to analyze quantitatively the growth and production annual field crops that was originally developed for crops in European countries. It is the base model for Monitoring Agricultural ResourceS (MARS) Crop Growth Monitoring System (CGMS) in operational use for yield estimation in European Union. The model is of great potential in providing effective modeling of crops in the United States. The first step to adopt the model to be fit for applications to crop modeling in the US is to provide required parameters at any region and any time in the United States. In this study, several data sources have been identified and enabled to be readily fed into the models through standard, open, automatic, Web-based, online geospatial Web services. These Web services have the flexibility of accessing, re-processing, and customization to the models at different levels – from regional (i.e. counties, agricultural statistic districts) modeling to point (i.e. pixel) modeling because of their spatiotemporal capabilities. Three major data sources and parameters for WOFOST model are meteorological data, crop data, and soil data. Soil data are accessed and customized through standard Web Feature Service (WFS) request to the online services of Soil Survey Geographic Database (SSURGO). Crop data are retrieved from Web Coverage Service (WCS) from CropScape that serves Cropland Data Layer (CDL). Assimilated data from ground observations provide meteorological observations. Meteorological observations are retrieved online through public service application programming interface (API) of DayMet that provide gridded estimates of daily weather parameters for North America, including daily continuous surfaces of minimum and maximum temperature, precipitation occurrence and amount, humidity, shortwave radiation, snow water equivalent, and day length. Workflow is enabled to support the on-demand customization and live feeding to WOFOST modeling. The services enable the parameterization process in WOFOST modeling.**

Keywords*— *WOFOST, model parameterization, crop growth model, open geospatial Web services, CropScape, CDL, SSURGO, Daymet, WCS, WFS

I. Introduction

WOFOST (WOrld FOod STudies) is widely used in Europe for crop growth modeling and simulation[1]. Parameterization for WOFOST has been established through several long-running projects, including the adoption of WOFOST as the base model in the Monitoring Agricultural ResourceS (MARS) Crop Growth Monitoring System (CGMS) in the Joint Research Centre of European Commission[2]. Using of WOFOST in the United States needs proper parameterization for WOFOST that is important since it affects the accuracy of yield estimation[3].

This study uses modular approach to develop and implement the retrieve, process, and prepare required parameters for WOFOST model that are suitable for its application in USA. Workflow is leveraged to compose the modules to form the integrated program to complete all the steps. The rest of the paper is organized as follows. In the second section, WOFOST model is described with the emphasis of determine input requirements. In the third section, parameterization for three major input parameters is discussed in details with implementation diagram. In the forth section, results are presented and discussed. Usage of open geospatial Web services is discussed. Finally, conclusive remarks and future direction are presented in the fifth section.

II. WOFOST

A. Overview of WOFOST Model

WOFOST model incorporates three modules – potential growth model, water limited growth model, and nutrient limited growth model[4]. Figure 1 shows the overall architecture of WOFOST and running configuration files. The core of the models are modeling and simulating the crop growth with photosynthesis under different conditions. It outputs a series of production levels on roots, stems, storage organs, and leaves.

B. InputRequirements of WOFOST Model

In order to run the WOFOST model, three input parameters and a series of configuration files are required, as shown in Figure 1. These are represented as input files to be prepared and provided. These files are described as follows.

1) Directory file: This file is an overall configuration file for WOFOST model. It specifies directories for weather data,

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crop data, soil data, run option, and temporary directory. With this file, the configuration of all running directories for WOFOST model can be customized and specified. At the level of directories, the directory file also implicitly determines where to look for runopt.dat – a file specifies fullpaths to specific configuration files. The running option is determined in ${RUNDIR}/runopt.dat where ${RUNDIR} is the value found as a property in the directory file.

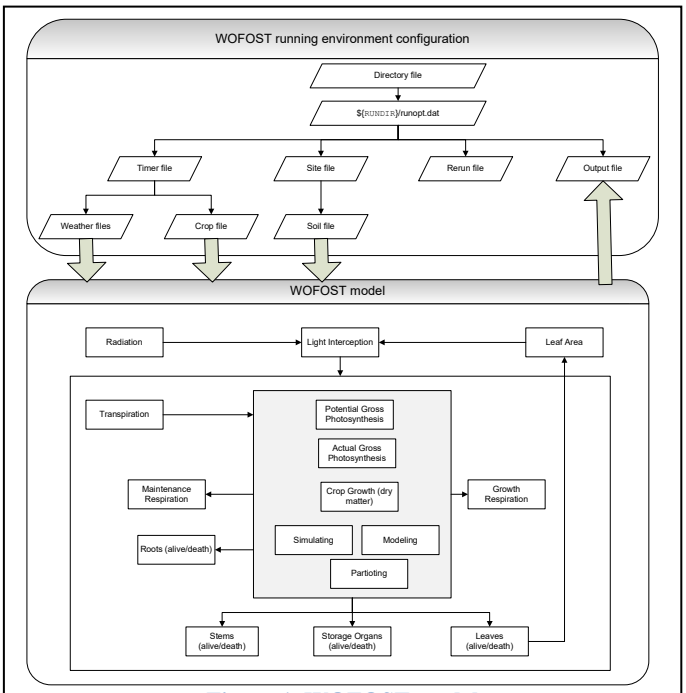

Figure 1. WOFOST model

2) Run option file: The runopt file further species four files in addition to general options for running WOFOST model. They are timer, site, rerun, and output which further specify crops and weather, soil, re-run options, and output directory respecively.

3) Weather files: The files provide meterologically related variables for the model. The series of files represent time series over years. Weather files are specified by prefix. The name pattern of weather files are in *.[0-9][0-9][0-9], as expressed in regular expression. File extensions are the last three digits of year. Each file holds a year of weather data. The paraemters include daily irradiation, minimum temperature, maximum temperature, vapour pressure, precipitation, and mean wind speed.

4) Soil file: This file provides paraemters that characterize the soil properties of the site. Each soil species has a file. It specifies physical soil charateristics (i.e. soil water retention, hydraulic conductivity, and soil workability parameters).

5) Cropfile: This file provides parameters that chraterize crop properties. Different crops have different set of properties. There are ten major crops in USA that have related models, including corn, soybean, cotton, peanut, rice, spring wheat, winter wheat, barley, sorghum, and oats.

III. Methodology for WOFOST Input Parametrization

WOFOST model needs several files configured properly to be run. There are two groups of configuration files. One is for the system configuration files that specify directory and file names to be used in program execution. They can be set up once depending on the purpose of the modeling and the computer system used. There should not be much change once the model execution environment is decided. They are best to be set up through a set of configuration files.

Another group is the actual data files for the model to be run against. These are the focus of this parameterization paper to deal with. There are three major input datasets for the model to run against. They are weather data, crop data, and soil data. The methodology for each input preparation is discussed in separate subsections followed. The overall approach is to access online data to prepare the input files using open geospatial Web services if possible to simplify and harmonize the interoperation at levels of data and services.

A. Weather

Daymet[5] is used as the primary source for preparing the weather file. Figure 2 shows the data flow for accessing, preprocessing, and producing the required weather input file for WOFOST. Daymet has several Web services, including Thematic Real-time Environmental Distributed Data Services (THREDDS) services and representational state transfer (REST) Application Program Interface (API). This study uses the RESTAPI. It takes the following form to access individual pixels.

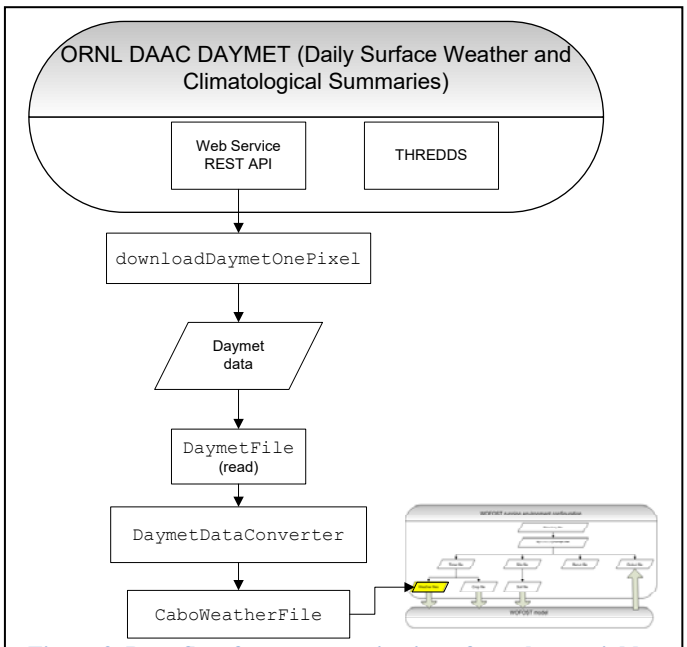

Figure 2. Data flow for parameterization of weather variables in WOFOST model

https://daymet.ornl.gov/data/send/query?lat=${***Latitude***}&lon=${***Longitude***}&year=${***Years***}

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where, ${latitude} and ${longitude} define the location of an interested pixel and ${Years} specify which years are included.

Table I shows how to map variables from Daymet to variables in CaboWeahter, the format used for WOFOST. More variables can be directly mapped to those across the two systems except unit conversion.

TABLE I. CONVERSION FROM DAYMET TO CABOWEATHER

#	Mapping from Daymet to CaboWeather		
	Daymet	***Conversion***	***CaboWeahter***
1	year		year
2	day		day
3	dayl[a]	srad*dayl/1000.0	Irradiation[b]
4	srad[c]		
5	tmax[d]		maxT[e]
6	tmin[f]		minT[g]
7	vp[h]	vp/1000.0	vaporP[i]
8	prcp[j]		precip[k]

a. In Daymet: (W/m^2),Incident shortwave radiation flux density
b. In CaboWeather: irradiation (kJ m-2 d-1).
c. In Daymet: (W/m^2),Incident shortwave radiation flux density.
d. In Daymet: (deg c),Daily maximum 2-meter air temperature.
e. In CaboWeather: maximum temperature (degrees Celsius)
f. In Daymet: (deg c),Daily minimum 2-meter air temperature.
g. In CaboWeather: minimum temperature (degrees Celsius)
h. In Daymet: (Pa) Water Vapor Pressure..
i. In CaboWeather: vapour pressure (kPa)
j. In Daymet: mm/day), Daily total precipitation
k. In CaboWeather: precipitation (mm d-1)

B. Soil

The Soil Survey Geographic Database (SSURGO)[6] is used as the primary source for preparing soil property input. It provides standard OGC-compliant Web Feature Service (WFS). This study accesses data through standard WFS API. The following shows the general form of API.

http://sdmdataaccess.sc.egov.usda.gov/Spatial/SDMWGS84Geographic.wfs?SERVICE=WFS&VERSION=1.1.0&REQUEST=GetFeature&TypeName=mapunitpoly&MaxFeatures=10&BBOX=***${longitude}***,***${latitude}***,***${maxlongitude}***,***${maxlatitude}***

Where, ${longitude}, ${latitude}, ${maxlongitude}, ${maxlatitude} represent minimum longitude, minimum latitude, maximum longitude, and maximum latitude respectively, which define a geospatial bounding box for data access. Figure 3 shows the data flow to access and prepare soil input parameter.

Table II shows how to map variables from SSURGO to soil variables in WOFOST model. SSURGO has layered description of soils. Weighted average is used to aggregate the layered data to derive the soil physical parameters required by the model.

TABLE II. CONVERSION FROM SSURGO TO WOFOST SOIL

#	Mapping from SSURGO to WOFOST soil		
	SSURGO	***Conversion***	***soil***
1	mukey	"S"+mukey	name
2	sandtotal_r[a]	Compute the top soil layer's texture by combining them in sand, clay, and silt composition. Use the combined compostion to look up the closestly resembed soil for their soil water retntion	SMTAB[d]
			CRAIRC[e]
			CONTAB[f]
3	claytotal_r[b]		SOPE[g]
			KSUB[h]
			SPADS[i]
4	silttotal_r[c]		SPODS[j]
			SPASS[k]
			SPOSS[l]
			DEFLIM[m]
5	wfifteenbar_r[n]	Weighted average of wfifteenbar_r in top soil layer over components	SMW[o]
6	wthirdbar_r[p]	Weighted average of wthirdbar_r in top soil layer over components	SMFCF[q]
7	dbthirdbar_r[r]	Weighted average of 1-(dbthirdbar_r/partdensity) in top soil over components	SM0[t]
8	partdensity[s]		
9	ksat_r[u]	Weighted sum of ksat_r over hzthk_r and compct_r	K0[x]
10	hzthk_r[v]		
11	comppct_r[w]		

a. In SSURGO: total sand
b. In SSURGO: total clay.
c. In SSURGO: total silt.
d. In WOFOST: soil water retention table.
e. In WOFOST: critical soil air content for aeration [cm3/cm3].
f. In WOFOST: hydraulic conductivity table.
g. In WOFOST: maximum percolation rate root zone[cm day-1].
h. In WOFOST: maximum percolation rate subsoil [cm day-1].
i. In WOFOST: 1st topsoil seepage parameter deep seedbed.
j. In WOFOST: 2nd topsoil seepage parameter deep seedbed.
k. In WOFOST: 1st topsoil seepage parameter shallow seedbed.
l. In WOFOST: 2nd topsoil seepage parameter shallow seedbed.
m. In WOFOST: required moisture deficit deep seedbed.
n. In SSURGO: volumetric content of soil water retained at a tension of 15 bars (1500 kPa).
o. In WOFOST: soil moisture content at wilting point [cm3/cm3]
p. In SSURGO: volumetric content of soil water retained at a tension of 1/3 bar (33 kPa).
q. In WOFOST: soil moisture content at field capacity [cm3/cm3]
r. In SSURGO: oven dry weight of <2 mm soil material per unit volume soil at a water tension 1/3 bar.
s. In SSURGO: specific gravity.
t. In WOFOST: soil moisture content at saturation [cm3/cm3]
u. In SSURGO: amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient
v. In SSURGO: A measurement from the top to bottom of a soil horizon throughout its areal extent.
w. In SSURGO: percentage of the component of the mapunit.
x. In WOFOST: hydraulic conductivity of saturated soil [cm day-1].

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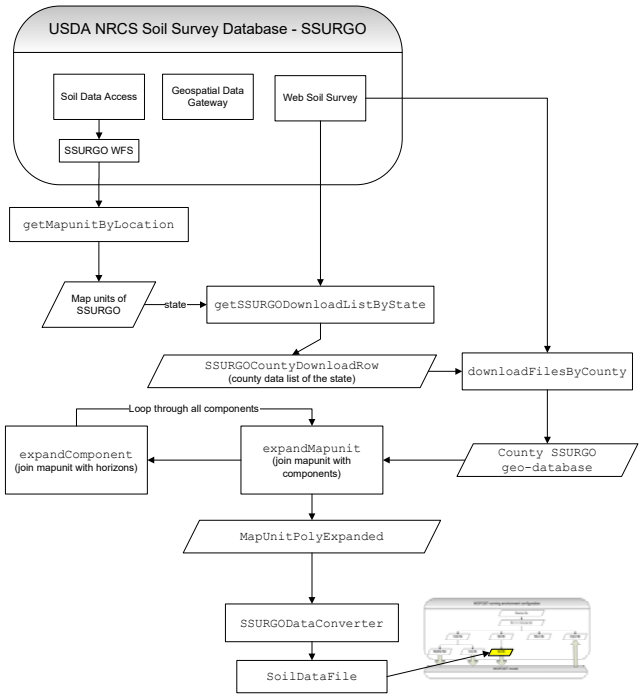

Figure 3. Data flow for parameterization of soil variables in WOFOST model

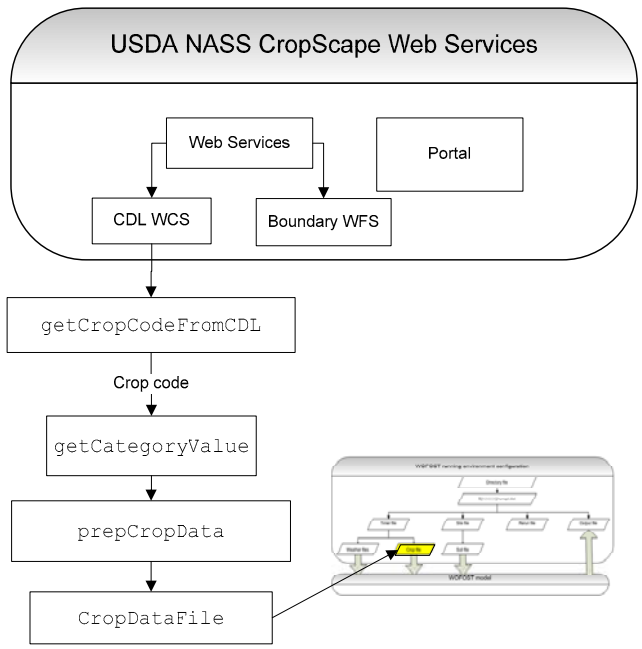

Figure 4. Data flow for parameterization of crop variables in WOFOST model

C. *Crop*

The parameters for crops differ from crop type to type. In order to associate the proper crop parameters with the models, the parameterization should return the proper crop parameter given a location. The crop type can be determined using the Cropland Data Layer (CDL) of USDA NASS. The Web services of CDL, CropScape provides the OGC-compliant Web Coverage Service (WCS) to disseminate the data[7]. Figure 4 shows the diagram of program flow to access, process, and prepare crop input data.

The resulted implementation is done using Java programming language. The command line access takes the following form which shows the easy and straightforward realization of the function for end users. Only location and year are required as input. The rest steps are done by the program to access the online resource via CropScape and crop property database.

```
java -Djava.util.logging.config.file=logging.properties -Dorg.yugenong.db.DBUtil.configuration=CropModel.xml -jar CropModel.jar -pc ${latitude} ${longitude} ${year}
```

Where, ${latitude} and ${longitude} specify the location and ${year} specify which year. The program sends a request the CropScape WCS service to retrieve data at a specific location.

IV. Results and Discussions

The parameterization enables the simulation of crop growth in any state of contiguous United States that consists of the 48 adjoining U.S. states plus Washington, D.C.

A. *WOFOST model outputs*

The implantation was done using Java programming language. The integrated model parameterization program needs only three parameters, i.e. location in latitude/longitude or projected x/y coordinates in Albers Equal Area coordinate reference system and year. The following shows the command line command to execute the parameterization program and invoke the WOFOST model. The form resembles what is used to describe crop parameterization program in the previous section. This is of no coincidence, but it represents each parameterization step require only location and year as input. Other data are accessed through online data services.

```
java -Djava.util.logging.config.file=logging.properties -Dorg.yugenong.db.DBUtil.configuration=CropModel.xml -jar CropModel.jar -cm ${latitude} ${longitude} ${year}
```

The integrated program adopts the design strategy of workflow composition of modular programs and Web services. Each individual step is implemented and wrapped with unified interfaces. Workflows are embedded to chain individual modules together to complete all the steps to prepare complete set of parameters for WOFOST model.

The integrated program prepares all the required parameters and executes the WOFOST model to derive various outputs. In this study, yield is one of the most interesting outputs. Figure 5 and Figure 6 show one example result for location (latitude, longitude) = (40.707, -95.848) and year 2014. The location was identified as corn. In Figure 5, the development stage is estimated. In Figure 6, different partition of growth is estimated, including leaves (WLV), storage (WSO), and stem

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(WST). WSO is the yield of corn. In this example, the yield is estimated as 8023 kilogram per hectare.

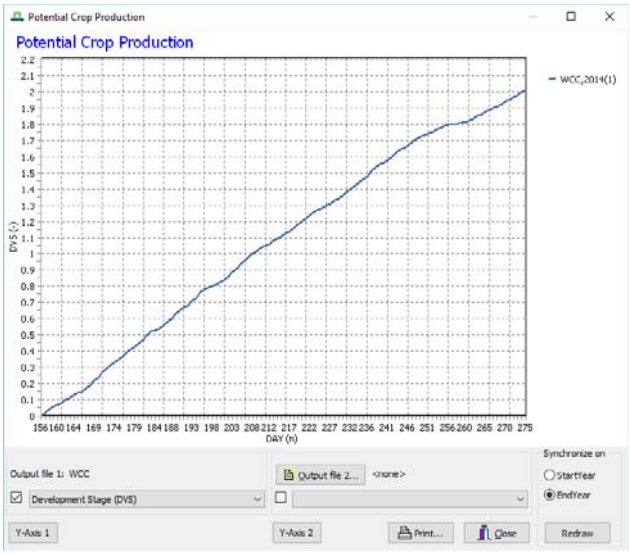

Figure 5. Development Stage (DVS) output of the WOFOST model

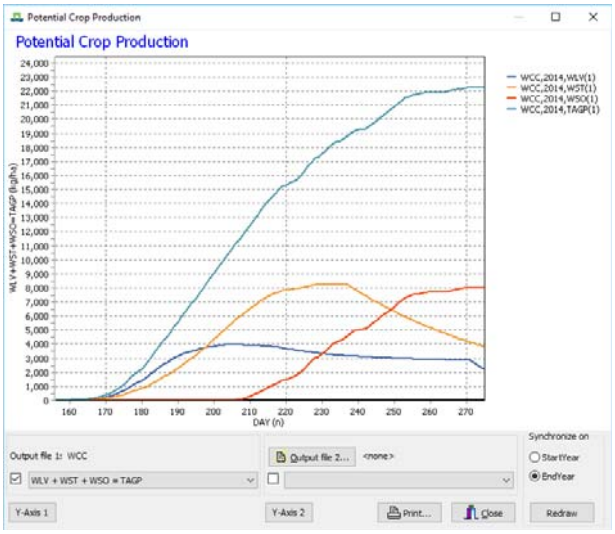

Figure 6. Production output from WOFOST model

Table IV shows some more example outputs from using the parameterization program for the year of 2014. With the online geospatial Web services, any given location of the contiguous 48 states of USA can be properly parameterized for the WOFOST model. In the example given, soybean and corn are found and estimated. The yield estimation produces reasonable results for soybean and corn. More rigorous validation is needed to further verify and optimize the parameterization for using of WOFOST model in USA.

B. Scaling and geospatial registration

Using of open geospatial Web services played an important role in easy implementation and parameterization for WOFOST. The online resources are discovered and re-used through open geospatial Web services. In this study, three different types of geospatial Web services were used. They are OGC-compliant WFS to access soil data from USDA NRCS data services, OGC-compliant WCS to access CDL data from USDA NASS CropScape data services, and THREDDS service to discover and access weather data from Daymet. Open specifications facilitates the open access to these data sources. The implementation of the client becomes an easy task of reusing existing library and toolkit that support such open geospatial specifications. Information extraction and re-using become possible with such open geospatial Web services.

TABLE III. CONVERSION FROM SSURGO TO WOFOST SOIL

Crop	Location (Albers equal area projection) and yield		
	Coordinate X[a]	*Coordinate Y*	*Yield*[b]
soybeans	-50053	2192169	5030
Soybeans	-50053	2193169	5013
Soybeans	-47053	2199169	5069
Soybeans	-45053	2248169	4968
Corn	2275174	387232	9043
Corn	2274874	295903	9221
corn	2274054	290854	9255
corn	2275078	287753	9240

a. Coordinates are in USGS version Albers Equal Area projection. Units are in meters.

b. Yield is in kg/ha, i.e. kilogram per hectare.

The open geospatial Web services also support certain well-documented functions when the services are released following the specification. In this study, two functions were found very useful in supporting often required scaling and spatial re-projection. Sub-setting and rescaling are supported by both WFS and WCS. Along with multiple coordinate reference systems support, it is possible to align and register the data from different scales and projection in their original form.

Alignment of information at specific location is important for the parameterization of WOFOST model input data. The open geospatial Web services are geospatial-aware. They facilitate sub-setting at user's customized request. This enables the retrieval of information to match the specified spatial resolution. To certain extent, these capabilities facilitate the scaling/registration of different parameters at a given location.

In this study, soil data ranges from 1:12,000 to 1:63,360. Weather data are interpolated to 1 kilometer resolution. CDL data are mostly 30 meter resolution and partially 56 meter resolution. Each of the data source has different native spatial reference systems. With the support open geospatial Web services, they all support common geographic reference systems. Alignment and re-scaling become easy with such open geospatial Web services.

V. CONCLUSIONS

The parameterization enables the simulation of crop growth in any CONUS state. Parameterization of WOFOST is

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developed for the contiguous United States (CONUS) via online, open geospatial Web services. Three data sources are used to retrieve, prepare, and execute the WOFOST model for any location in CONUS between 2008 and 2015. Some states can also support data starting from 2000. The limitation of incomplete coverage is due to the lack of CDL data to identify crop type. The CDL may not be available for certain states between 2000 and 2007 since they do not have full coverage. The results of yield estimation on corn and soybean are reasonably accurate with such parameterization.

Further study will focus on validation and optimization of the parameterization for WOFOST with extensive and aggregated comparison against surveyed data at county levels. Inclusion of limiting factors (such as flooding, drought) will be studied to assess the applicability and sensitivity of WOFOST to such factors.

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